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12.3 CORE OPERATING LIMIT SUPERVISORY SYSTEM (COLSS)

Learning Objectives:

1. State the purpose of the core operating limit supervisory system (COLSS).
2. List the operating limits that are monitored by COLSS.

12.3.1 Introduction

The COLSS consists of process instrumentation and algorithms implemented by the plant computer to continually monitor the limiting conditions for operation on peak linear heat rate (LHR), margin to departure from nucleate boiling (DNB), total core power, azimuthal tilt and axial shape index (ASI).

The COLSS continually calculates DNB margin, peak LHR, ASI, total core power, and azimuthal tilt. COLSS then compares the calculated values to the limiting condition for operation on these parameters. If a limiting condition for operation is exceeded for any of these parameters, COLSS alarms are initiated by the plant computer and operator action is taken as required by technical specifications.

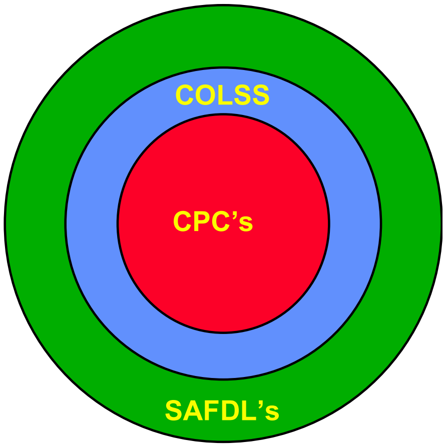
The selection of limiting safety system settings (LSSS), core power operating limits, and the azimuthal tilt operating limit are specified such that no safety limit will be exceeded as a result of an anticipated operational occurrence (AOO) and that the consequences of postulated accidents will be acceptable. The reactor protection system (RPS) functions to initiate a reactor trip at the specified LSSSs.

The COLSS is not required for plant safety since it does not initiate any direct safety-related function during AOOs or postulated accidents. The technical specifications define the limiting conditions for operation (LCO) required to ensure that reactor core conditions during operation are no more severe than the initial conditions assumed in the safety analyses and in the design of the low DNBR and high local power density trips. The COLSS serves to monitor reactor core conditions in an efficient manner and provides indication and alarm functions to aid the operator in maintenance of core conditions within the LCOs given in the technical specifications.

The COLSS algorithms are executed in the plant computer. The calculational speed and capacity of COLSS enables numerous separate plant operating parameters to be integrated into three more easily monitored parameters:

1. Margin to a limiting core power (based upon margins to DNBR, peak linear heat rate and licensed power limits),
2. Azimuthal tilt and
3. Axial shape index.

If COLSS were not provided, maintenance of reactor core parameters within the LCOs, as defined by the technical specifications, would be accomplished by monitoring and alarms on the separate non-safety related process parameters used in the COLSS calculations. Therefore, the essential difference in using COLSS in lieu of previous monitoring concepts is the integration of many separate process parameters into a few easily monitored parameters. The conciseness of the COLSS displays has distinct operational advantages, since the number of parameters that must be monitored by the operator is reduced.



The concept of COLSS was proposed in the core protection calculator (CPC) patent application. The CPCs and COLSS work together to assure that the CPCs are able to protect the Specified Acceptable Fuel Design Limits (SAFDLs) such that DNBR will never drop below 1.2, nor will linear heat rate rise above 21 kW/ft in the event of AOOs.

Since it is the class IE CPCs which actually provide the reactor trip, then one might expect that the CPCs could also be used to maintain the LCOs on DNBR and LHR, and the COLSS need not concern itself with these LCOs. The CPCs do in fact perform this function if COLSS is out of service. Technical specifications sections state that the appropriate LCOs on DNBR and LPD can be maintained by monitoring these parameters on the CPC remote modules. So why the desire to have a COLSS?

The answer is that the CPCs must be very fast and reliable to provide protection for the design basis AOOs and accidents, whereas COLSS can take the time to provide a more accurate calculation of core DNBR or LPD. COLSS can also use inputs which, although more accurate than those used by the CPCs, are less reliable. The result is that COLSS is more accurate than the CPCs. The CPC calculations must be biased to be conservative to offset their inaccuracy, so that the CPCs will normally calculate a value of DNBR that is lower, and a value of LPD that is higher than those calculated by COLSS.

It is therefore possible to operate with COLSS out of service; however the DNBR and ASI used are from the most restrictive CPC, thus it will likely be necessary to reduce power below 100% to be in compliance with the technical specifications. Stated another way, COLSS allows the core to be operated at a higher power density (higher power level) than would be possible with CPCs alone, and the CPCs and COLSS together allow much higher power densities than those which were possible with previous protection systems.

12.3.2 COLSS Design Requirements

COLSS is designed to assist the operator in implementing those sections of the technical specification requirements for monitoring of the following LCOs:

1. Thermal margin,
2. Linear heat rate,
3. Azimuthal tilt and
4. Axial shape index.

COLSS also assists the operator in maintaining core power equal to or below Rated Thermal Power (RTP).

To implement these requirements, COLSS is required to perform the following functions:

1. Compute the thermal margin power operating limit LCO from process variable measurements,
2. Compute the peak linear heat rate power operating limit LCO from process variable measurements,
3. Compute the azimuthal tilt index and monitor it with respect to the LCO on azimuthal tilt,
4. Compute the axial shape index and monitor it with respect to the LCO on axial shape index,
5. Compute plant power from process variable measurements,
6. Compute the margin to the licensed power, peak linear heat rate, and thermal margin power operating limits and
7. Initiate appropriate alarm sequences and informative messages when any monitored margin or parameter exceeds its LCO.

The power operating limits are calculated such that no AOO will cause a SAFDL to be exceeded when initiated from inside the COLSS initial margin and proper plant protection system (PPS) action occurs and no postulated accident will have consequences more severe than those predicted in the safety analysis when initiated from inside the COLSS initial margin and proper PPS action occurs.

The LCOs are calculated using algorithms which have been designed with adequate time response for the following plant operating conditions:

1. Normal steady state operation at any power between 15 percent and 100 percent of licensed power,
2. Normal, controlled changes in unit load at any rate up to five percent per minute at any power between 15 percent and 100 percent of licensed power and
3. Step changes in unit load of up to 10 percent initiated at and ending at any power between 15 percent and 100 percent of licensed power.

12.3.3 COLSS LCOs

The design of the monitoring and protective systems are integrated with the plant technical specifications (in which operating limits and limiting conditions for operation are specified) to assure that all safety requirements are satisfied. The plant monitoring systems, protection systems, and technical specifications thus complement each other. Protection systems provide automatic action to place the plant in a safe condition should an abnormal event occur. The technical specifications set forth the allowable regions and modes of operation on plant systems, components, and parameters. The monitoring systems (meters, displays, and systems such as COLSS) assist the operating personnel in enforcing the technical specifications requirements. Making use of the monitoring systems, protection systems and technical specifications in the manner described above will assure that all anticipated operational occurrences or postulated accidents will have acceptable consequences if the following conditions are satisfied.

1. The operating personnel maintain all protective systems settings at or within allowable values,
2. The operating personnel maintain actual plant conditions within the appropriate limiting conditions for operation and
3. Equipment other than that causing an abnormal event or degraded by such an event operates as designed.

12.3.3.1 DNBR LCO

Note that item 2 above implies that the operator must maintain LCOs in order for the protection system to properly function. The CPCs can provide timely protection for DNBR only if the operator maintains the steady state DNBR in accordance with technical specifications. This allows ample margin between steady state DNBR and the trip setpoint so that DNBR protection is assured, even in the event of a rapid DNBR reduction.

Core parameters affecting the margin to DNB are continually monitored by COLSS, and a core power operating limit based on margin to DNB is computed. Operation of the reactor at or below this operating limit ensures that the most rapid DNB transient that can result from an AOO does not result in a DNB reduction to a value less than 1.20.

12.3.3.2 LPD LCO

The core power distribution is continually monitored by COLSS, and a core power operating limit based on peak linear heat rate is computed. Operation of the reactor at or below this operating limit assures that the peak linear heat rate is never more adverse than that postulated in the loss of coolant accident (LOCA) analyses. This will maintain the clad surface temperature below 2200°F in the event of a LOCA. Note that the LCO on linear heat rate is not based on protecting the 21 kW/ft LHR SAFDL in the event of AOOs. In this case, the concern of clad surface temperature in the event of a LOCA forces a lower kW/ft steady state operating limit than does the concern of exceeding 21 kW/ft in the event of AOOs. If the SAFDL requirement that the CPC LPD trip protects for LHR < 21 kW/ft during AOOs were the only concern, a higher steady state operating LPD could be permitted.

12.3.3.3 Licensed Power Level LCO

A core power operating limit based on licensed power level is also monitored by COLSS. Operation of the reactor at or below this operating limit ensures that the total core power is never greater than that assumed as an initial condition in the accident analyses.

12.3.3.4 Azimuthal Tilt LCO

The limitations on azimuthal tilt (Tq) are provided to assure that design safety margins are maintained. The azimuthal flux tilt is calculated in COLSS. The azimuthal flux tilt is not directly monitored by the plant protection system (PPS). This is because the CPCs each only monitor one of the four excore safety channels, making excore channel cross comparison impossible in the CPCs. The excores themselves can provide cross-comparison and that is used to determine azimuthal tilt if the incores are out of service.

Without the ability to cross compare excores, the CPCs are in essence blind to azimuthal tilt. For this reason, azimuthal tilt is an addressable constant in the CPCs. It is necessary for the operator to inform the CPCs of the correct value of azimuthal tilt by changing this addressable constant to reflect a Tq which is conservative with respect to the actual tilt.

COLSS normally calculates azimuthal tilt based on incore nuclear instrumentation, using symmetric sets of incores in the four core quadrants to determine a valid tilt. This calculation is performed on line, as is the case with all COLSS calculations. If the azimuthal tilt, as calculated by COLSS, exceeds that in the CPCs, a CPC tilt limit exceeded alarm will result on the plant computer CRT. Provisions are also made for plant annunciation on this alarm.

Note that the CPCs and COLSS do not communicate with each other, since the CPCs are safety related, while the COLSS is not. It is therefore necessary for the operator to inform the COLSS as to the value of azimuthal tilt assumed in the CPCs. To accomplish this, plant computer prompting should be followed. Initially, the CPCs assume an azimuthal tilt of 2%, so this value should be entered in COLSS as the alarm setpoint. If the tilt increases, and new values of azimuthal tilt are entered into the CPCs, these same values must be entered by the operator into the COLSS to be used for the alarm setpoint.

If the azimuthal tilt rises to 10%, a second alarm (technical specification tilt limit exceeded) will occur on the plant computer alarm CRT. There are also provisions for annunciation on this alarm. This alarm warns the operator that the azimuthal tilt has reached the maximum allowed for normal operation as defined in the technical specifications. An azimuthal tilt of 1.10 should normally not occur but if it does, power reduction is required.

12.3.3.5 Axial Shape Index LCO

The LCO on ASI assures the actual value of ASI is maintained in the range assumed in the safety analysis.

12.3.4 System Description

12.3.4.1 COLSS Input/Outputs

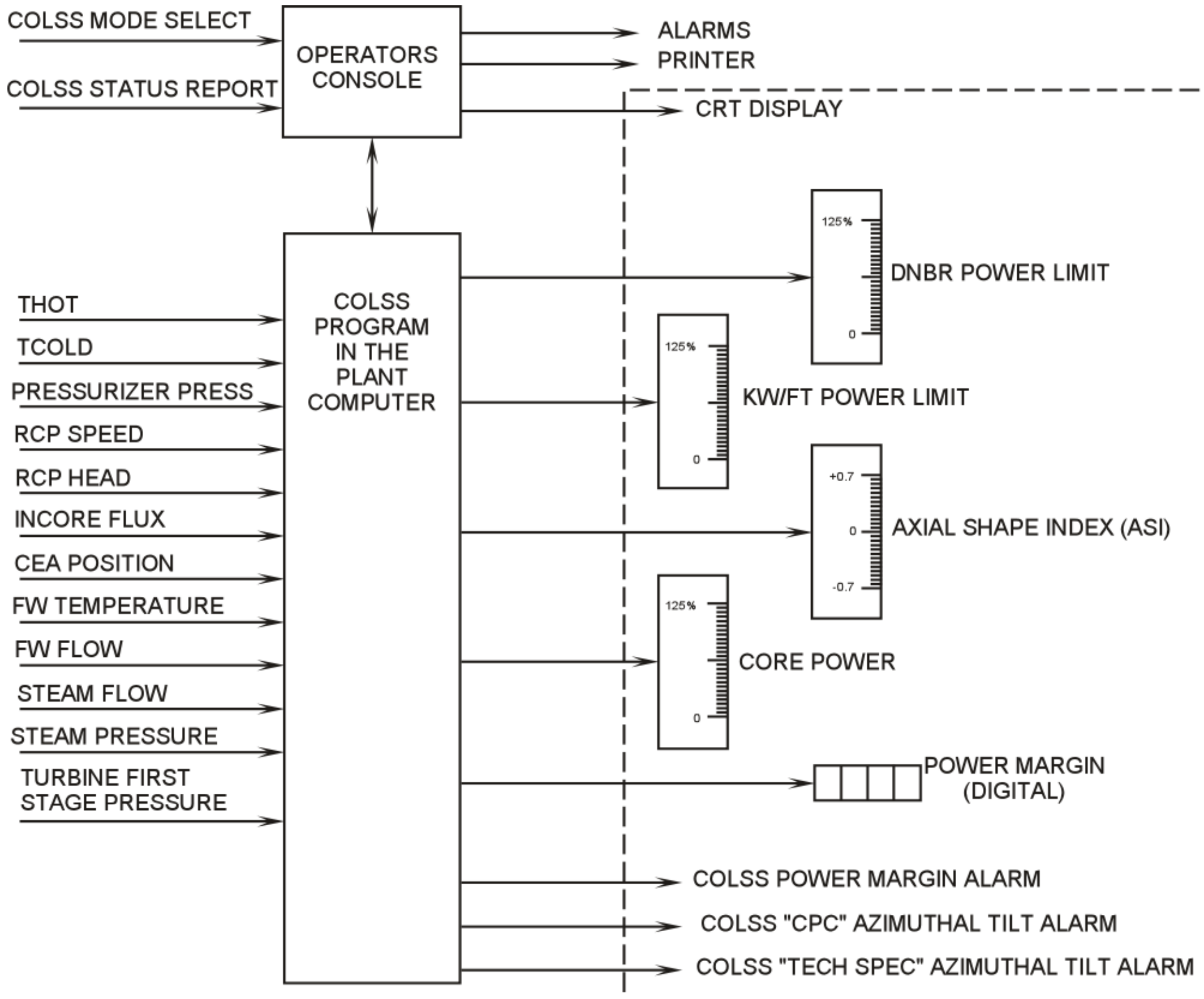
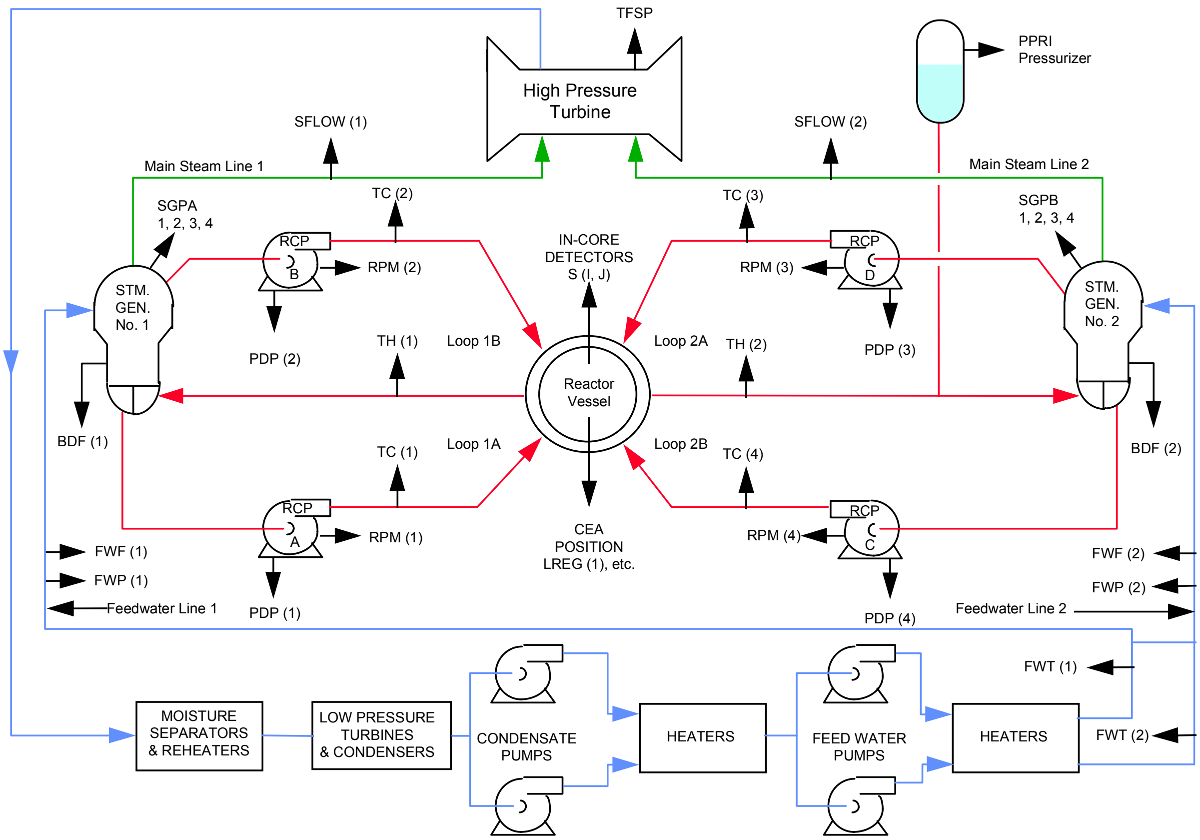


Figure 12.3-1 Core Operating Limit Supervisory Systems (COLSS)

Figure 12.3-1 shows all COLSS inputs and outputs. Since COLSS is in essence a program resident in the plant computer, there is no COLSS hardware to speak of with the exception of the process inputs and outputs. The inputs are the same inputs as those used for other programs and data logging.

COLSS MONITORED VARIABLES

Figure 12.3-2



12.3.4.2 Contact Outputs

All contact outputs are used to provide plant annunciation; however in addition to those alarms on the plant annunciator panels, alarm messages will also be displayed on the plant computer alarm CRT, for these and many other conditions affecting COLSS.

In addition to the four contact outputs described below, COLSS will also print out a number of alarm messages for a variety of conditions affecting COLSS, including all sensor validity check failures, cross check failures, and the designation of any calculated block as bad.

12.3.4.3 COLSS Power

Margin Alarm

This alarm is set (contacts open) if:

1. COLSS is not in scheduled mode (that is, COLSS has been turned off),
2. Licensed power is exceeded. This licensed power limit will normally be 100%, but can be any lower limit as imposed by the NRC licensing letter ,
3. Either Power Operating Limit (POL) is exceeded. The two POLs are the DNBR POL and the LPD POL. These limits represent the maximum power the core could produce (based on current power distribution as sensed by process inputs) without violating the LCO on DNBR or LPD or
4. Plant power or a POL has a bad validity.

It is instructive to note that in COLSS actual power is not an input to the COLSS POL calculation. This contrasts with the CPCs where power is an input to the DNBR and LPD calculations. The reason for this is that the CPCs must calculate the actual DNBR and LPD for protection purposes, whereas COLSS calculates the hypothetical power the plant could safety produce without exceeding the LCOs on DNBR or LPD.

The COLSS margin alarm actually will alarm if the most restrictive of the licensed power, DNBR POL, or LPD POL is exceeded by actual plant power.

COLSS has extensive self diagnostic capability, particularly with regard to input sensor out-of-range failures. Although COLSS also does have the ability to, in some cases, substitute backup sensors for failed sensors, if COLSS determines that there are inadequate inputs to give the desired output, it will declare the block of calculations affected by the input as bad. All outputs from the affected block will therefore also be bad, and any blocks downstream may be declared bad, unless there is an alternate input block which can be substituted. This latter case exists in the COLSS method of selecting plant power, in which three different methods of power measurement are employed. Should one be declared bad, COLSS uses logic to eliminate the faulty calculation.

Opening contacts to the COLSS power margin alarm will also cause one or more of the following messages to be printed on the alarm CRT, as applicable:

DNBR POWER LIMIT EXCEEDED
KW/FT POWER LIMIT EXCEEDED
LICENSED POWER LIMIT EXCEEDED
INSTANTANEOUS DNBR POWER
LIMIT EXCEEDED
INSTANTANEOUS KW/FT POWER LIMIT EXCEEDED
LPL ALARM DURATION EXCEEDED
DNBR ALARM DURATION EXCEEDED
KW/FT ALARM DURATION EXCEEDED
ANNUAL LPL VIOLATION
ANNUAL DNBR VIOLATION
ANNUAL KW/FT VIOLATION

The first three alarm messages are derived directly from the COLSS power margin alarm.

12.3.4.4 CPC Azimuthal Tilt Exceeded Annunciator.

If the azimuthal tilt, as calculated by COLSS, exceeds that assumed by the CPCs alarm contacts will be opened. Several alarm messages associated with this alarm will also be printed on the alarm CRT, including:

CPC TILT LIMIT EXCEEDED
CPC TILT ALARM DURATION EXCEEDED
CPC TILT ALARM ANNUAL DURATION EXCEEDED.

The latter two show the time since onset of the condition, and the total time, on an annual basis, that the alarm condition has been set.

12.3.4.5 Technical Specification Tilt Limit Exceeded Alarm

This alarm has a setpoint of 1.10, which is the maximum azimuthal tilt allowed for normal operation in accordance with technical specifications. Messages on the alarm CRT associated with this annunciator include:

TECHNICAL SPECIFICATION TILT LIMIT EXCEEDED
TECHNICAL SPECIFICATION TILT ALARM DURATION EXCEEDED
TECHNICAL SPECIFICATION ALARM ANNUAL DURATION EXCEEDED.

12.3.4.6 ASI Alarm

This is not a contact output from the COLSS, therefore it does not warrant notice on Figure 12.3-1. However, COLSS does monitor ASI, and there are provisions for the following Alarm CRT Outputs:

ASI OUT OF LIMITS
ASI ALARM DURATION EXCEEDED
ASI ANNUAL DURATION EXCEEDED.

12.3.4.7 Analog (Indicator) Outputs

The following COLSS meters on the control board provide continuous (on line) information to the operators:

1. Core power operating limit based on peak linear heat rate (kW/ft POL; 0-125%),
2. Core power operating limit based on margin to DNB (DNBR POL; 0-125%),
3. Total core power (0-125%),
4. Margin between core power and nearest core power operating limit (Power Margin; -50 to +125%) and
5. Core average axial shape index (-.7 to +.7)

The power margin meter has a horizontal scale and is a digital display. It represents the difference between actual plant power, as calculated by COLSS, and the most restrictive (lowest) of DNBR POL, LPD POL and licensed power limit.

As long as COLSS is in service, and the surveillance requirements have been met, there is no reason to consult technical specifications or to worry about exceeding the limits, since the COLSS margin would go to zero and a COLSS power margin alarm would be set if the LCOs on these parameters were exceeded.

12.3.5 COLSS Functional Diagram

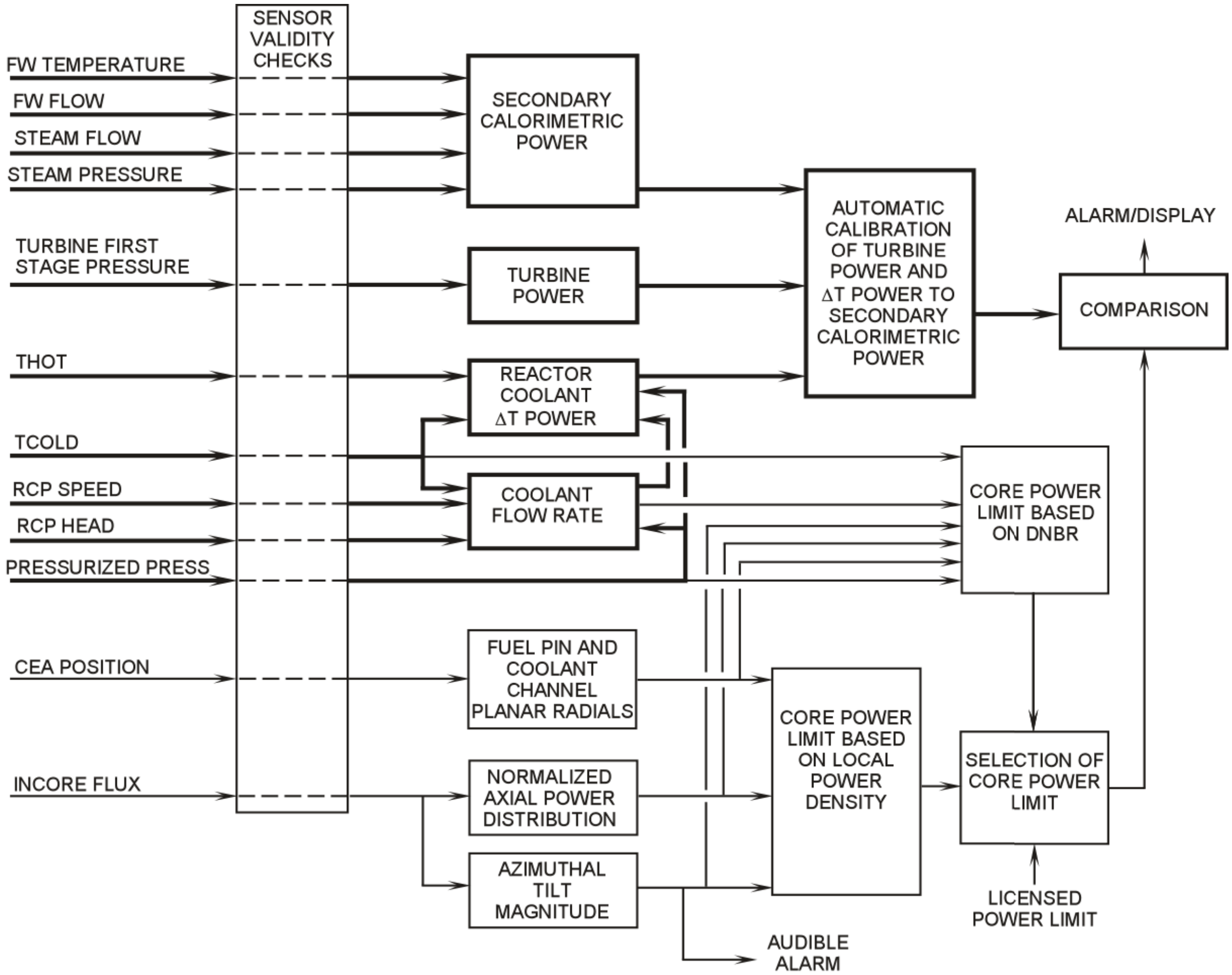


Figure 12.3-3 Functional Diagram of Core Operating Limit Supervisory Systems (COLSS)

Figure 12.3-3 is a functional diagram of COLSS. COLSS sections pertaining to the calculation of plant power for use in the plant power indicator and the margin calculation have been highlighted, whereas those sections of COLSS involving power distribution and the generation of the POLs have not. The reason for this is that COLSS can, at least functionally, be thought of as being comprised of two sections. One section performs the power calculation; and the other performs the POL calculation.

Strictly speaking, these are not totally independent, since plant power is an input to the in-core burnup calculation and the radial peaking factor lookup table, both of which are used in the power distribution algorithms used in the POL calculation. However, plant power in this application is a second order effect, that is, plant power should not be thought of as an input to the POL calculation since the power operating limit is accomplished by determining the current power distribution in the core and then assuming various increasing power levels until a hypothetical power is chosen which, based on the current power shape, violates the LCO on DNBR, or LPD.

Hypothetical power limits like this one are calculated independently for both DNBR and LPD and the DNBR POL and LPD POL indicators are the result. Normally, with all CEAs withdrawn, and equilibrium xenon, both of these power limits should read well above 100% since to do otherwise would imply that the plant cannot reach 100% power without violating a LCO.

Plant power is, on the other hand, calculated independently, and the derived plant power is compared to the most restrictive of the DNBR POL, LPD POL, or licensed power, and the difference is read out on a power margin digital indicator. If the margin drops to zero, the power margin alarm will be present.

12.3.5.1 Plant Power Calculation

The inputs to the plant power calculation are shown in Figure 12.3-3. Prior to actually being used in any plant power calculations the inputs must be examined for validity. That is, COLSS will determine if the inputs are reading properly.

This is done in two ways:

Range Check -This check insures that the sensors are in range. If not, they are declared bad. If bad sensors are discovered, they will be alarmed, and they may be automatically replaced by COLSS with substitute sensors that are identical or similar. In some cases, no replacement sensors are provided, and COLSS alarms the condition to the operator on the alarm CRT and awaits operator response. Where no replacement is available the calculation based on the failed input is halted and the quality of the block is set to bad.

Cross Check - COLSS looks at two sensors monitoring the same parameter and alarms if their difference exceeds a dead band value. No automatic replacement is done, since COLSS doesn't know which is faulty (they're both in range). It just alarms to the operator on the alarm CRT that the cross check has failed. It is then up to the operator (or I&C technician) to determine the reason for the failure.

In summary, three different power level measurement techniques are employed by COLSS:

reactor coolant ΔT power,
secondary calorimetric power, and
turbine power (based on a correlation of core power with turbine first stage pressure).

The reactor coolant ΔT power is a less complex algorithm than secondary calorimetric power and is performed at a more frequent interval (every second for ΔT power, versus every 30 seconds for the more detailed and accurate secondary calorimetric power). The secondary calorimetric power is used as a standard to periodically adjust the gain coefficient on the calculation of reactor coolant ΔT power. This arrangement provides the benefits of the secondary calorimetric accuracy and the reactor coolant ΔT power speed of computation.

The reactor coolant ΔT power is calculated based on the reactor coolant volumetric flow rate (calculated from RCP speed and ΔP), the reactor coolant cold leg temperature, and the reactor coolant hot leg temperature. The reactor coolant ΔT power contains a dynamic term which provides a rapid indication of power changes during transients. The static form of the equation used is:

$$\dot{Q} = \dot{m} c_p (T_h - T_c) \ .$$

The secondary calorimetric power is based on measurements of feedwater flow rate, feedwater temperature, steam flow, and steam pressure. A detailed energy balance is performed for each steam generator. The energy output of the two steam generators is summed and allowances are made for reactor coolant pump heat, pressurizer heaters, and primary and secondary system energy losses. The secondary calorimetric power is very accurate at steady state, but due to the system response characteristics is less accurate during transients.

The turbine power is calculated based on turbine first stage pressure. Turbine power provides a leading indicator of core power changes in response to load changes.

The best features of the ΔT power and turbine power measurements are obtained by calibrating them to secondary calorimetric power in a manner that, at steady state, the calibrated powers equal the more accurate secondary calorimetric power. During transients calibrated powers closely track their respective uncalibrated powers affording the dynamic tracking ability of the latter. This calibration is performed with a long time constant ranging from 15 minutes to 2 hours, depending on final data constants. The long calibration time constant assures that for quick transients the response of ΔT power and turbine power are retained, but that in steady state, the more accurate secondary calorimetric will dominate.

12.3.5.2 Power Calculations

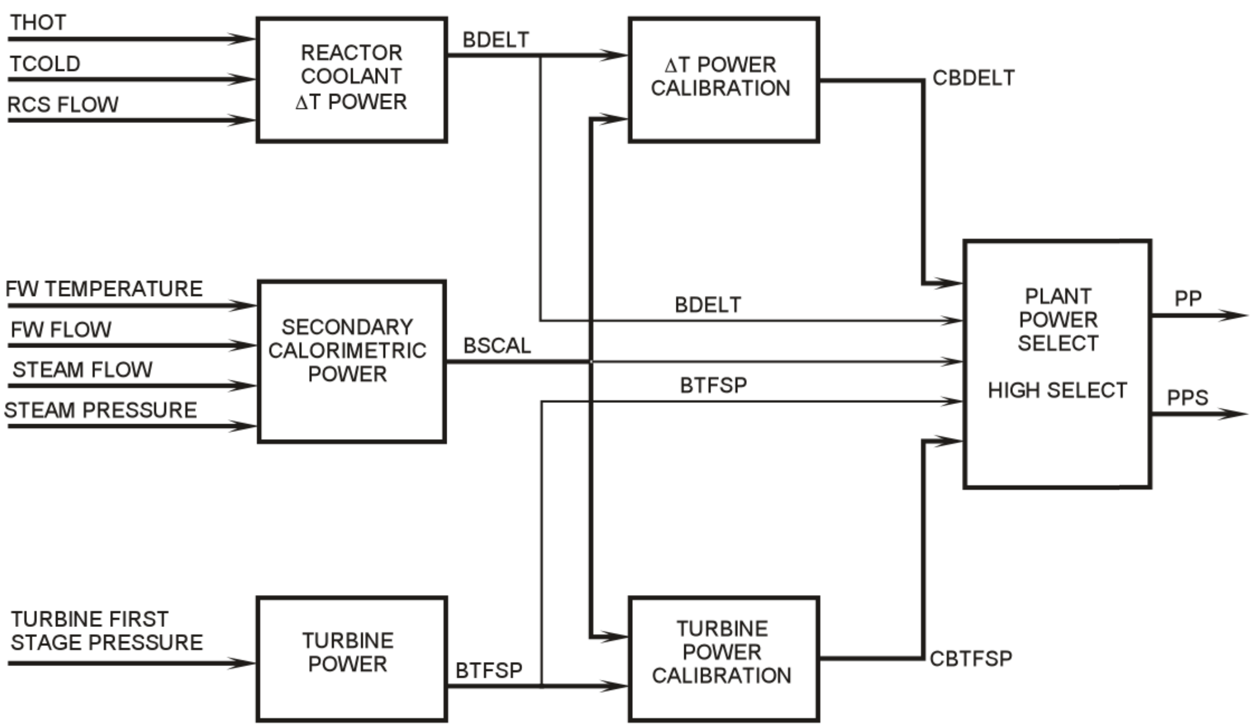


Figure 12.3-4 Power Calculations - Normal Power Operation Above 15%

Figure 12.3-4 shows the power selection logic used in the COLSS. The highlighted lines show the power calculations and power selection logic used when above 15% reactor power. A detailed description of each of these blocks follows.

Reactor ΔT Power Calculation

The primary calorimetric power (BDELT) is calculated based on the compensated hot and cold leg temperatures (T_h and T_c), pressurizer pressure, and reactor coolant mass flow rate (TMFLOW). The determination of BDELT involves the use of a static power term which calculates the enthalpy rise across the core and a hot leg dynamic power term. Calculation of BDELT is performed every second with values transmitted to both the plant power select operation and the ΔT power calibration.

Turbine Power Calculation

The turbine power (BTFSP) is calculated using a correlation based on turbine first stage pressure (TFSP) acquired from the process inputs. The value of turbine power is sent to both the plant power selection and the turbine power calibration. BTFSP provides a relatively fast indication of core power change due to load changes. It is calculated every second.

Secondary Calorimetric Power

Calculations

The purpose of the secondary calorimetric is to calculate the reactor power based on a secondary side energy balance and the system energy losses and credits.

The inputs to the power calculation include feedwater flow, feedwater temperature, secondary pressure and steam flow rate. The COLSS calculates the energy transferred to each steam generator by standard thermodynamic methods.

Energy losses of the system include losses from letdown flow, coolant pump seals, cooling water flow, all the primary coolant leaving the system, coolant piping and other losses from the nuclear steam supply system.

Energy credits are obtained from charging pump operation, reactor coolant pump operation, pressurizer heaters, and other sources of electrically generated heat.

The secondary calorimetric power (BSCAL) is finally calculated by summing the energy of the steam generator and the energy losses and credits. The result of this 30 second calculation is used in the plant power selection (PPS) operation and the ΔT/Turbine power calibration.

It must be noted that the steam flow sensor is not used to derive steam flow in the secondary calorimetric. Steam flow is derived from:

Steam Flow = Feed Flow - Blowdown Flow.

Feed Flow is a sensed variable, however, blowdown flow is a constant fed into the plant computer by the operator. Failure of the operator to use the correct value for blowdown flow will therefore result in an erroneous secondary calorimetric calculation. This secondary calorimetric is used to calibrate the ΔT and TFSP powers to the more accurate secondary calorimetric value. Furthermore, this same BSCAL is used as the plant power measurement during daily calibration of excores and CPCs to match plant power.

Therefore, if this power measurement is improper, all power measurements used in the safety system will be improper. This is obviously not desirable, and it is extremely important that the operator be certain of the accuracy of the secondary calorimetric calculation, and be wary of sudden or gradual changes in plant electrical output for a given thermal power

Errors similar to this have been made at plants prior to the advent of COLSS, where erroneous feed flow indication and subsequent errors in reading power resulted in plant operation above 100% power.

12.3.5.3 Δ T and Turbine Power Calibration

The purpose of this operation is to calibrate the ΔT power (BDELT) and the turbine power (BTFSP) to the secondary calorimetric power (BSCAL). This update is performed every second.

The calibrated ΔT power (CBDELT) is found by summing BDELT and a current calibration term, calculated in the COLSS program.

Similarly, the calibrated turbine power (BTFSP) is found by summing BTFSP and the current turbine calibration term.

The values of CBDELT and CBTFSP which are calculated every one second are then sent to the plant power select operation.

12.3.5.4 Plant Power Selection

The function of the plant power selector is to determine the larger of the calibrated primary power (CBDELT) or the calibrated turbine power (CBTFSP) for use as plant power level (PP). This section also calculates a margin bias and has alternate selection logic which is used when one or more of the inputs is determined to be of bad validity.

A second function of the plant power selection is the calculation of a biased plant power for use by the power dependent insertion limit CEA application program.

12.3.5.5 Alternate Power Selection Logic.

The choice of the larger of CBDELT or CBTFSP is only valid when above 15% power, when the secondary calorimetric is being performed (it is not performed below 15% power).

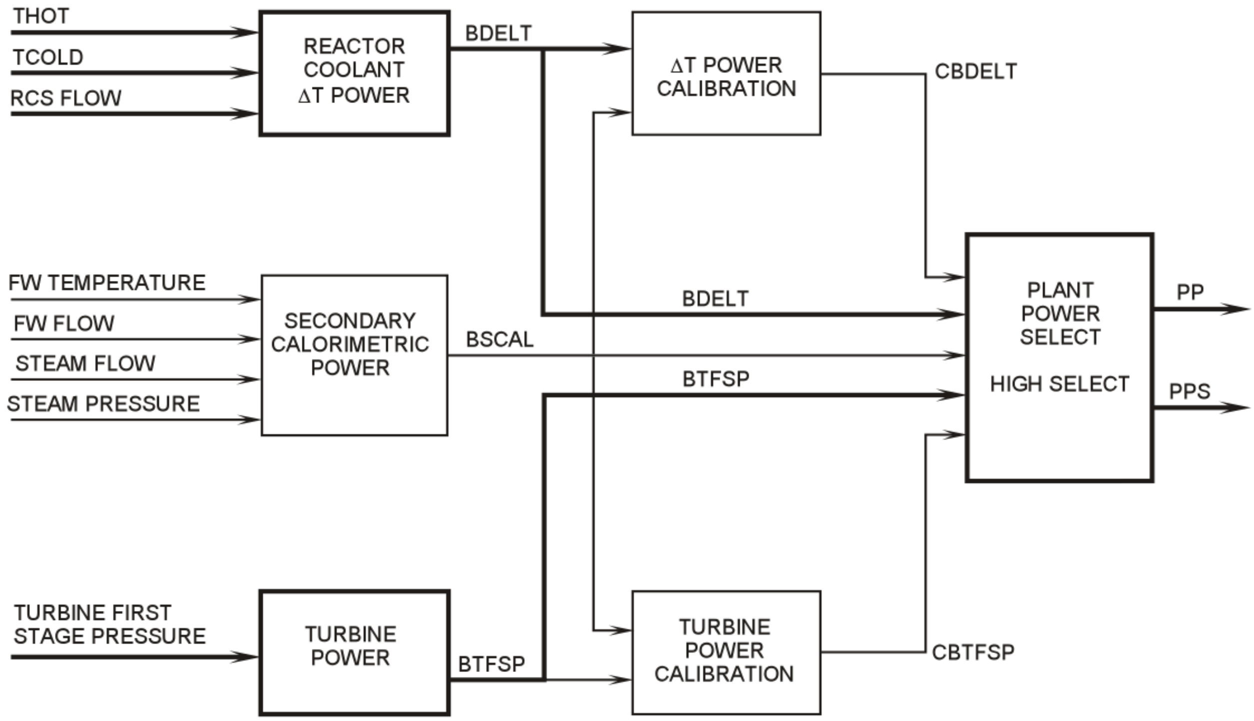


Figure 12.3-5 Power Calculations - Power Operation Below 15% or With BSCAL Bad

When below 15% power, CBDELT and CBTFSP will be bad because BSCAL is bad by virtue of its not being run. In this case, COLSS selects the larger of the uncalibrated ΔT power (BDELT) or turbine first stage pressure power (BTFSP) for plant power, as shown in Figure 12.3-5. As power increases above 15%, as indicated by the highest of BDELT or BTFSP, per the plant power selection logic, a sudden step change in power may be observed on the COLSS power meter as plant power switches to the highest of CBDELT or CBTFSP.

If the secondary calorimetric is bad due to sensor failures, the COLSS uses the same alternate power selection logic, selecting the highest of uncalibrated BTFSP or BDELT.

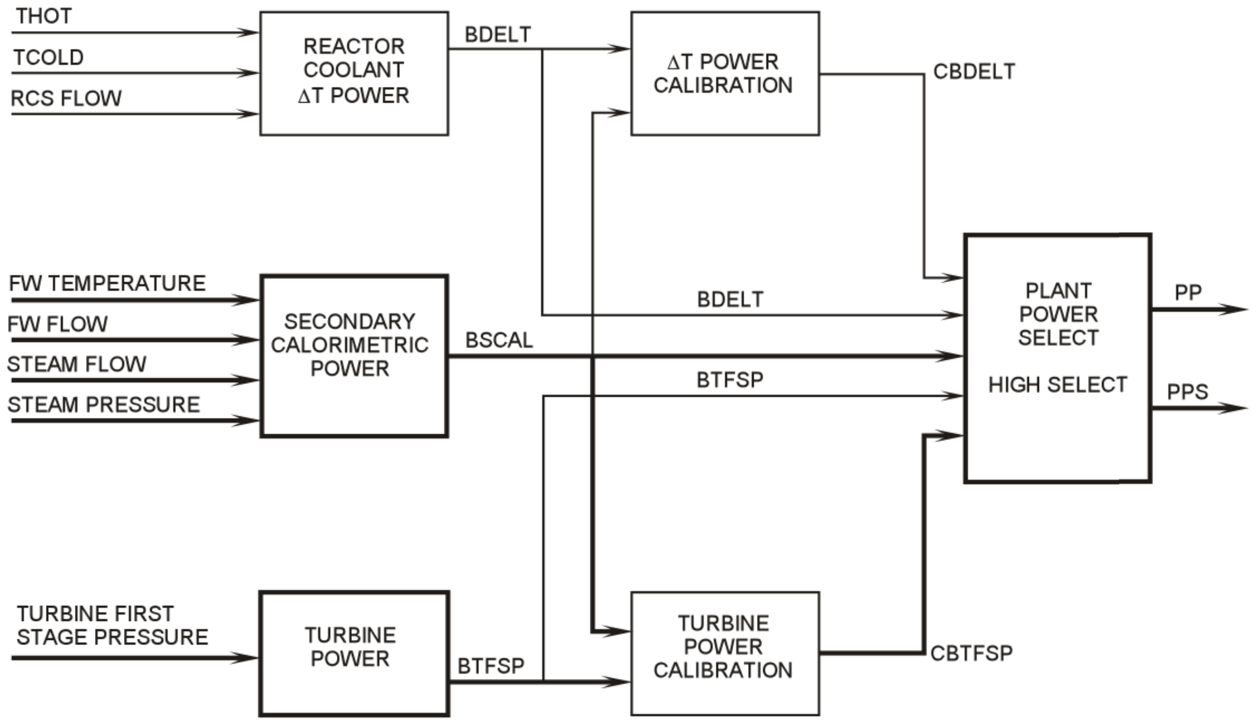


Figure 12.3-6 Power Calculations - Power Operation Above 15%, BDELT Bad

Figure 12.3-6 shows a different situation. Here ΔT Power is bad. It is more unlikely for this to happen than for secondary calorimetric power to fail because BDELT and BTFSP inputs all have alternate sensor selection logic if one sensor goes out of range. That is, all sensors used in other than the secondary calorimetric calculations have a backup sensor which is automatically substituted by COLSS for the failed (out of range) sensor.

If ΔT power should fail, COLSS selects the highest of secondary calorimetric or calibrated turbine first stage power, as shown in Figure 12.3-6.

It is interesting that one plant with CPCs (ANO-2) runs normally in this configuration because the quality of BDELT is set to bad. This stems from the T_h anomaly problem, in which primary calorimetric calculations when above 80% power are considered invalid due to incomplete coolant mixing in the hot legs.

In general, the following are true:

1. If a block is bad, the block fed from that block will also be bad. For example, if BSCAL is bad, CBDELT and CBTFSP are bad and not used in power selection.
2. If a block fails, plant power will choose the highest of the remaining two blocks. For example, if BSCAL is bad, plant power is the highest of BDELT or BTFSP. If BDELT is bad, plant power is the highest of BSCAL or BTFSP.
3. If two power blocks are bad, then COLSS selects the remaining good power for plant power.
4. If all three power measurements are bad, plant power is bad, and COLSS is out of operation, setting the COLSS master alarm.

The only exception to this rule is on Failure of CBTFSP, in which case CBDELT is plant power.

Since plant power can be one of several different power measurements COLSS must take into account the accuracy of the different measurement techniques when using alternate plant power selection logic. This is accomplished by selecting different plant power biasing terms for each selection choice from a lookup table. The biasing term represents a conservative uncertainty factor added to the measured power.

12.3.6 Power Operating Limit Calculation

As stated previously, COLSS can be thought of as being made up of a power calculation, and a power operating limit calculation. Actual plant power is not a direct input into the POL calculation because the POL portion of COLSS is looking for the hypothetical power which the plant could be raised to without violating the LCOs on DNBR or LPD, based on current power distribution. COLSS therefore must calculate a power profile based on process inputs to derive the proper axial, radial, and azimuthal power profiles.

The inputs available to COLSS are similar to those available to the CPCs, but in many cases are more accurate. For example, the CPCs must rely on three levels of excore neutron detectors to provide power information, the COLSS uses five levels of incore detectors, centered at 10%, 30%, 50%, 70%, and 90% of core height. Furthermore, there are 56 such strings of in-cores scattered throughout the core. Therefore the axial power distribution as calculated by COLSS will be more accurate than that calculated by the CPCs

It is interesting that COLSS does not use incores to derive radial power distribution, although they would seem to be well suited to that application. Incores are used to derive radial power profile off line, using such programs as INCA or CECOR. However, these are time consuming. COLSS uses the quicker method of radial peaking factor lookup tables, as do the CPCs. COLSS lookup tables are more involved, and the CEA position measurement for COLSS is more accurate since it uses computer pulse counting rather than the reed switches used by the CPCs.

The combination of more accurate sensors, more detailed algorithms, and more computational time mean COLSS is, at least in normal system operation, more accurate than the CPCs. This increased accuracy translates into a less conservative DNBR POL than would have been calculated if the CPCs had been used, hence higher operating powers. With COLSS out of service, maintaining the DNBR POL per technical specifications will likely require a power reduction of as much as 10%.

12.3.6.1 Detailed Power Distribution Calculations

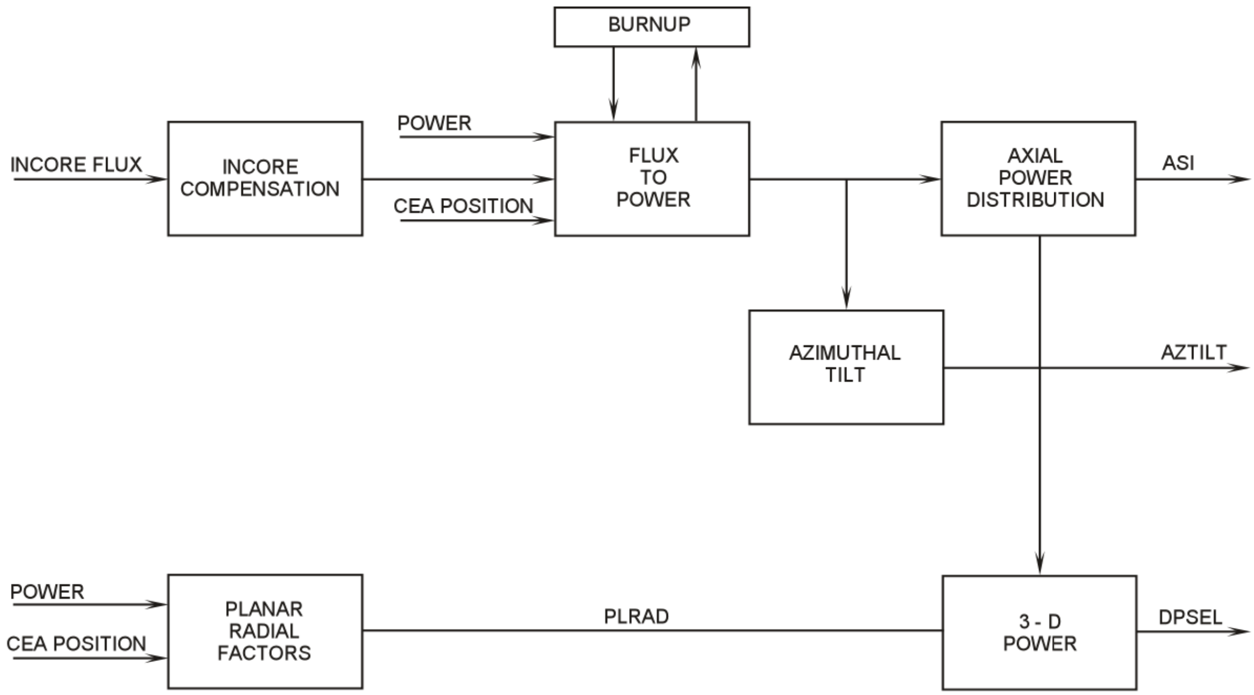


Figure 12.3-7 Power Distribution

The algorithm uses an axial and radial synthesis to construct a core hot pin power distribution. Incore detector signals are used to construct a core average axial power distribution. The axial power distribution is then combined with pre-calculated planar radial peaking factors appropriate to the various axial regions defined by differing control rod configurations. By combining the axial power distribution with axially dependent radial peaking factors, a pseudo hot pin power profile is established. This power profile is then increased by the amount of azimuthal flux tilt calculated from the several symmetric incore detector sets available. The resulting three-dimensional power peak and power distribution are used to calculate the linear heat rate power operating limit.

The core is regarded as being divided into several radial regions in the horizontal plane, selected by taking into account the locations of the CEA groups and the locations of the various generations of reload fuel. As many as five radial regions are allowed with the flexibility to use any lesser number provided through the appropriate selection of region wise constants. Axial power profiles in the hot pin are computed in each radial region for use in the margin computations. These power profiles are calculated using peaking factors which relate the power in the hot pin in each region to the core average power. Tables of these planar radial peaking factors are stored in COLSS as a function of CEA configuration resulting from normal sequential insertion of the CEAs. Thus, using the known CEA positions to define the axial profile of each unique CEA configuration, appropriate planar radial peaking factors are selected and combined with the core average axial shape to yield a hot pin axial power profile for each radial region.

The radial peaking factors stored in COLSS are predetermined from a set of rodded and unrodded power distributions, all of which assume the presence of an equilibrium xenon distribution corresponding to the full power, unrodded condition. However, radial redistribution of xenon following changes in CEA configuration can influence the planar radial peaking factors. This effect is neglected in the COLSS power distribution algorithms. The resultant small error is accommodated by inclusion in the overall COLSS uncertainty assessment.

Flux tilts are detected by comparison, at various levels in the core, of signals from symmetrically located sets of fixed incore detectors. The region wise power distribution data is corrected by application of the computed flux tilt before proceeding with the margin computations. Deviated single CEAs or out-of-sequence CEA groups, should these occur, are signaled to COLSS by the plant computer based pulse counting CEA position indicating system. Tables of conservatively large penalty factors are applied to the power distribution information.

These calculations are performed in six major blocks:

1. Detector signal to flux,
2. Flux to equivalent power,
3. Planar radial peaking factors,
4. Axial power distribution,
5. Azimuthal tilt calculation and
6. 3-D power distribution.

12.3.6.2 Incore Detector Signal Compensation

Dynamic compensation of the incore detector signals is performed to compensate the detector signal for the beta decay behavior of the rhodium detector element. COLSS utilizes a digital filter to compensate for the relatively slow incore detector dynamic response. This is necessary because the incores are self-powered. That is, they have no external voltage across them during operation. The detector output is a current which is in reality the sum of the electrons produced in the beta decay of the activated Rh^{l04} to Pd^{l04}. This decay follows two half lives, with the predominant one being 42 seconds. This is too slow, even for COLSS. COLSS dynamically compensates the incore output to, in effect, predict what the correct final detector current value will be based on a quick sample of the change in detector current produced during a power change.

12.3.6.3 Flux to Power Calculations

The incore detector compensated neutron flux is converted to relative power at each incore detector location. This process consists of three modules. Module one performs the flux to power calculation at each location and is performed at ten second intervals. Module two integrates the relative power for calculation of fuel burn-up factors and is also performed at ten second intervals. The third module calculates fuel burn-up factors from the integrated relative power signals and is performed on a daily basis.

12.3.6.4 Planar Radial Peaking Factors

Planar radial peaking factors are generated based on CEA group positions, calculated in the CEA scan program, and plant power. The calculations are performed as part of the 10 second group of calculations and are used in the determination of the 3-D power distribution.

12.3.6.5 Axial Power Distribution

The axial power distribution is calculated from the detector power signals using a numeric curve fit to an average detector string. That is, all incore detector readings on a given core level are averaged, and the average output at that core height is compared with the outputs from the other four heights to produce an axial power distribution. A new axial power distribution for an average detector string and a new axial shape index are calculated as part of the ten second group of calculations. The axial power distribution and ASI are used in the determination of the kW/ft plant operating limit.

12.3.6.6 Azimuthal Tilt Calculation

Azimuthal tilt is calculated from a number of selected axial rings of four incore detector strings at each axial level. At each level the detector ring tilts are averaged into a level average tilt. The level tilts are weighted and summed to construct a composite core average azimuthal tilt index. This calculation is part of the ten second block of calculations.

Two alarms are associated with azimuthal tilt. The lowest of these has a set point corresponding to the azimuthal tilt value used by the CPCs. The highest of these is the technical specification azimuthal tilt limit.

12.3.6.7 Three Dimensional Power Distribution

The purpose of the 3-D power distribution calculation is to synthesize a three-dimensional power distribution for use in the linear heat rate power operating limit calculation. This power distribution is synthesized by applying the fuel densification augmentation correction and planar radial peaking factors to the core average axial power distribution. The 3-D power calculation is performed as part of the 10 second block of calculations.

12.3.6.8 Power Operating Limit Calculation

The POL calculations in COLSS are primarily concerned with generating two distinct power operating limits, they are:

1. Linear heat rate POL (kW/ft) and
2. Thermal margin POL (DNBR).

The kW/ft power limit is calculated using the azimuthal tilt magnitude (AZTILT), and the 3-D power peaking factor distribution (DPSEL). kW/ft calculations are performed for 40 axial node positions, this in turn generates data for a pseudo hot channel model which conservatively establishes a POL. The kW/ft power limit is calculated as part of the 10 second block of calculations.

The thermal margin power limits are calculated as part of the 30 second block of calculations, however the DNBR POL update is performed every second.

The function of this area is to evaluate the core power operating limit (POL) based on the limiting thermal margin determined from DNBR, quality at the node of minimum DNBR, or void fraction. The limiting DNBR, quality, and void fraction are calculated and compared to predetermined limits. The core thermal power is the independent variable in these calculations. Core power is adjusted and the calculations are repeated until the DNBR, the quality at the node of minimum DNBR, and the void fraction meet specified convergence criteria. The calculation can be divided into four sections.

1. Core average pressure drop,
2. Closed hot assembly mass velocity iteration,
3. Open hot channel mass velocity iteration and
4. Thermal margin calculation and core power operating limit iteration.

The core average pressure drop is based on a subcooled fluid single axial node representation of the reactor core. The hot assembly, hot channel and core power operating limit calculations are based on 20 axial nodes. The minimum DNBR in the hot channel is compared against a specified limiting minimum DNBR. The axial node with the smallest difference between nodal equilibrium void fraction and its mass velocity dependent void fraction limit is defined to be the limiting void fraction node for the current value of POL. Increase in the POL will generally cause DNBR to decrease and cause void fraction and quality to increase. In addition, increasing the POL may cause the node of minimum DNBR or the limiting void fraction node to shift.

It should be noted that COLSS does not calculate the present DNBR, it merely performs an iterative procedure that substitutes values of plant power and underflow fractions with present core operation parameters to project what power limit will cause the DNBR to approach, but not exceed, its limiting value. Underflow fraction is the fraction of normal flow during a four pump loss of flow at which minimum DNBR occurs, once all system time delays are accounted for.

The zone update section reevaluates the axial shape index (ASI) and the maximum integral radial factor to determine if the initial radial zone chosen should still be the limiting one. Otherwise, one of the other four radial zones shall be used and the DNBR POL updated.

The plant operating limit update is performed at one second intervals. The present values of flow, primary pressure, cold leg temperature and power distribution are compared to the previous values used in the 30 second thermal margin calculation. If a significant difference is found the DNBR POL is updated to reflect the change in parameters.

12.3.7 Core Power Operating Limit Filtering and Alarm Annunciation

The power operating limit filtering provides continuous monitoring of plant power with respect to the licensed power limit and the calculated core power operating limits. Two separate checks are performed, an instantaneous check using unsmoothed power and unsmoothed POL, and a steady state check using smoothed power and smoothed POL. When unsmoothed plant power exceeds a power operating limit, an alarm sequence is started.

The alarm on the CRT will read instantaneous DNBR power limit exceeded or instantaneous kW/ft power limit exceeded as appropriate.

When smoothed plant power exceeds a smoothed POL, an alarm sequence is initiated. The alarm on the CRT will read DNBR POL exceeded, kW/ft POL exceeded, or licensed power limit exceeded, as appropriate.

The difference between smoothed and unsmoothed power is that the unsmoothed power is the value calculated every second, and will fluctuate in value as each calculation is made. The main control board (MCB) indicators for plant power, the DNBR POL and kW/ft POL are all derived from the unsmoothed power, as are the alarms listed above.

The unsmoothed power based alarms are actually biased, so that if the instantaneous power rises to the POL on DNBR or LPD, an alarm will not occur. The biasing term corresponds to 2% power on these instantaneous alarms, so that power must rise 2% above the POLs for the instantaneous alarms to initiate. This prevents spurious alarms caused by normal calculation fluctuations.

The smoothed plant power and power operating limits on the other hand, are filtered or averaged values. These are averaged over time to eliminate spurious fluctuations, and if the smoothed plant power should exceed the most restrictive of the smoothed DNBR POL, smoothed LPD POL, or licensed power, an alarm sequence will initiate. There is no 2% bias here. On the smoothed limits, if the plant power reaches the most restrictive limit, one of the three alarms previously described will result, as well as the COLSS power limit annunciator contacts being opened. The difference between the smoothed plant power and the most restrictive POL (kW/ft, DNBR, or licensed power) will be indicated on the MCB digital margin meter.

The filtering of the power operating limits and the plant power consists of a smoothing process utilizing a two stage averaging procedure. The first stage takes the average of the last 10 calculations, so that 10 seconds worth of data is averaged in a block. This block is then output to a second stage in which the 10 second block is averaged with the previous nine (9) 10 second blocks to produce a smoothed output. As new 10 second blocks are fed into the second stage, the oldest block is discarded, so that a 10 point running average results, with each of the 10 points representing in turn the average of ten individual one second calculations.

Plant technical specification surveillance requirements require that corrective action be taken when the plant power operating limits are exceeded in the steady state. To meet these requirements the length of time over which the reactor was operated with a margin alarm set must be measured and monitored for each event. For example, technical specifications specify that if kW/ft or DNBR should exceed their limits, corrective actions should be taken within 15 minutes. For this reason there are LPD alarm duration exceeded and DNBR alarm duration exceeded alarms, set for 15 minutes. If an alarm condition exists for 15 minutes, this alarm will set. This alarm is cleared once the alarm condition clears.

There are also provisions for annual violation alarms on DNBR, LPD, and licensed power. COLSS has a timer which keeps track of the total amount of time an alarm condition has been exceeded. When the power limit alarm resets, the clock does not reset, but rather awaits the next alarm condition, then adds the time of the new violation to the total. If technical specifications should specify a maximum amount of time per year that the alarm condition can be in, similar to the present requirement on CEA insertion limits, the annual violations alarm will be set when this limit is exceeded. There is presently no such time limit applicable to COLSS, but the feature is there. The annual duration timer must be manually reset at the plant computer.

12.3.8 Summary

COLSS continually calculates DNB margin, peak LHR, ASI, total core power, and azimuthal tilt magnitude and compares the calculated values to the limiting condition for operation on these parameters.

COLSS, in conjunction with the CPCs, allow the core to be operated at higher power densities than previous designs.

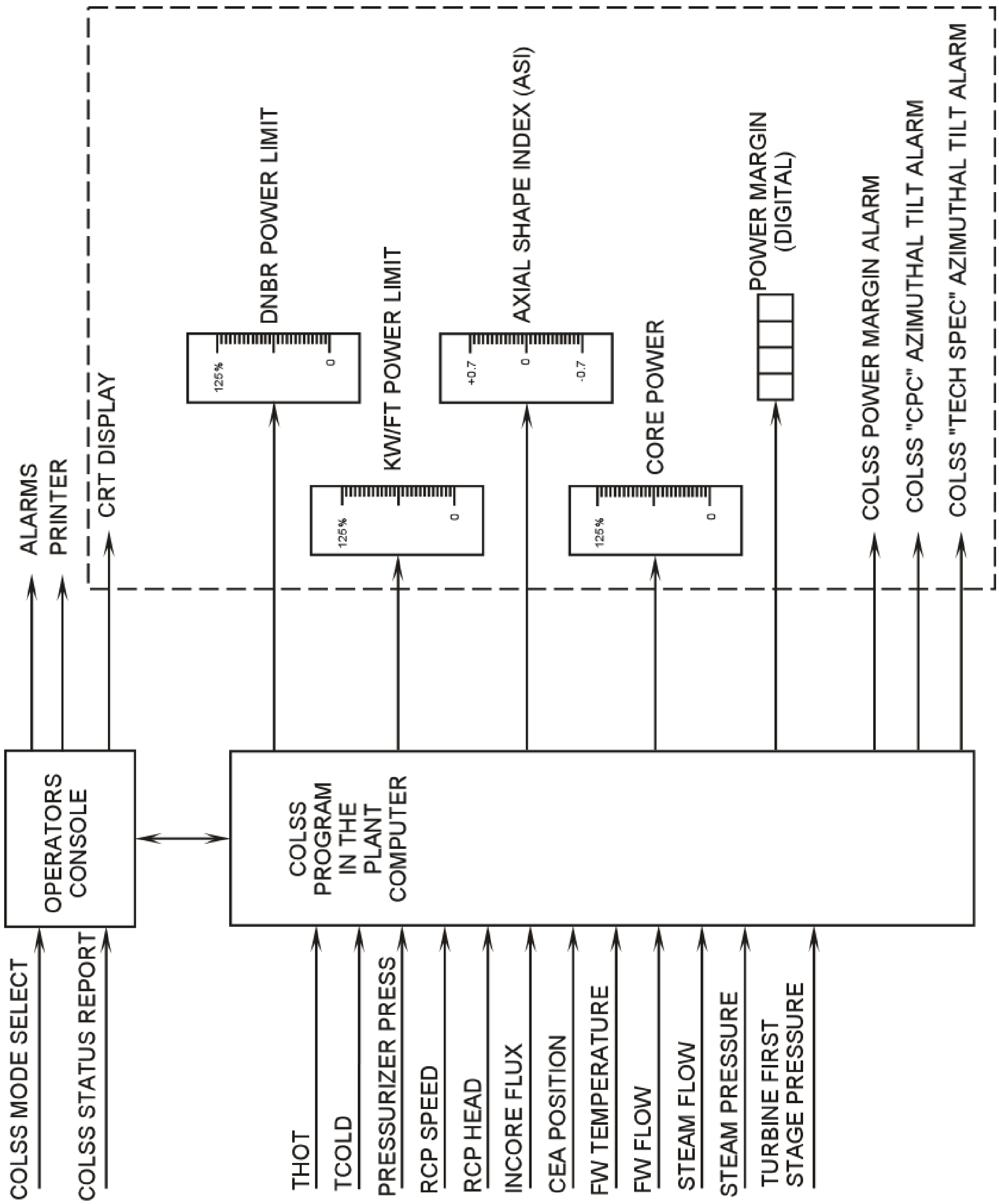


Figure 12.3-1 Core Operating Limit Supervisory System (COLSS)

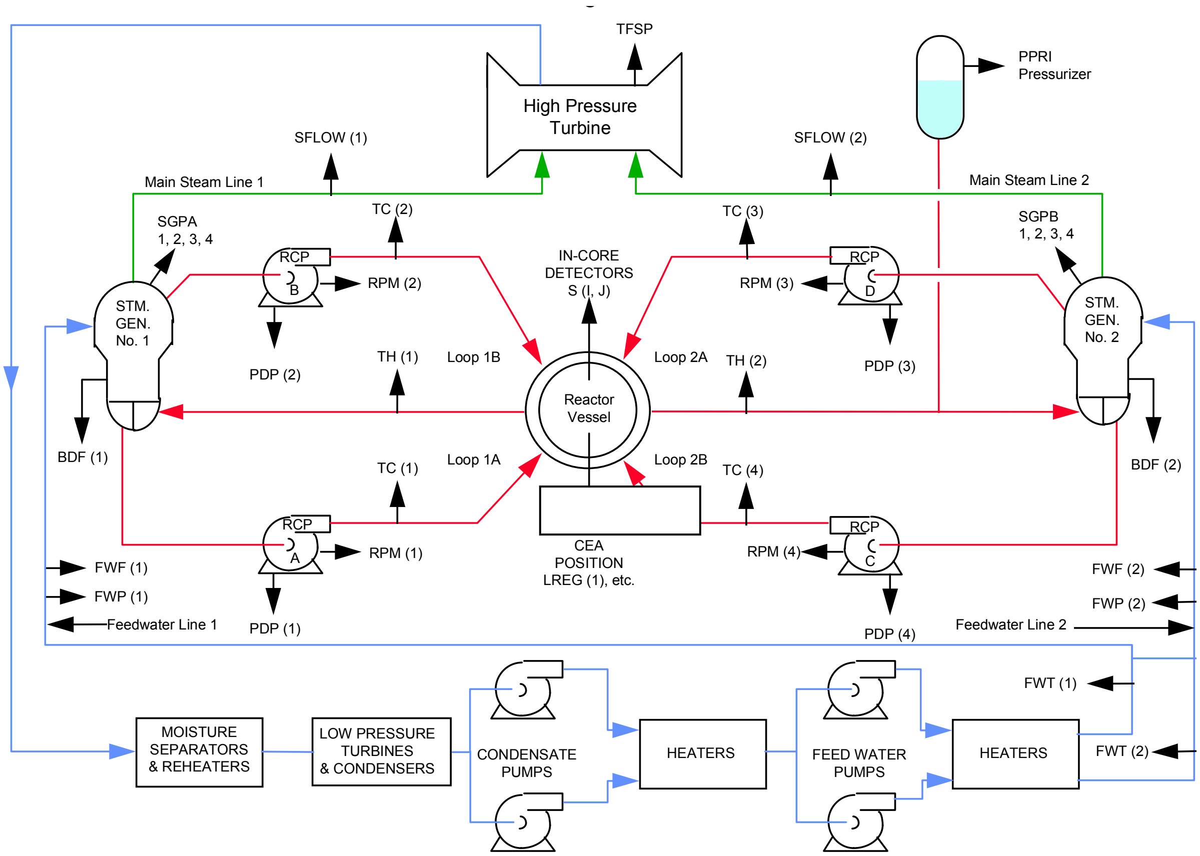


Figure 12.3-2 COLSS Monitored Variables

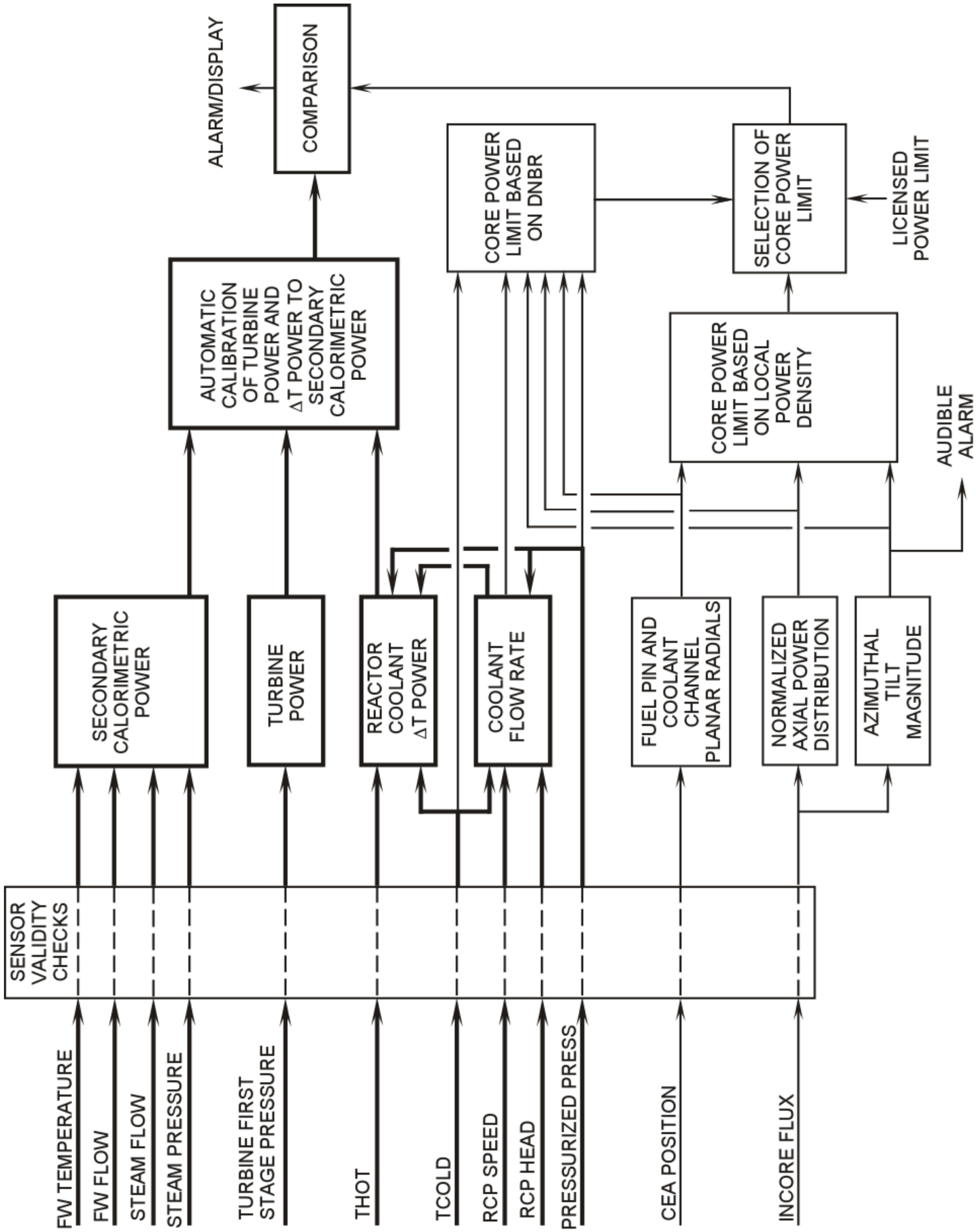


Figure 12.3-3 Functional Diagram of Core Operating Limit Supervisory System (COLSS)

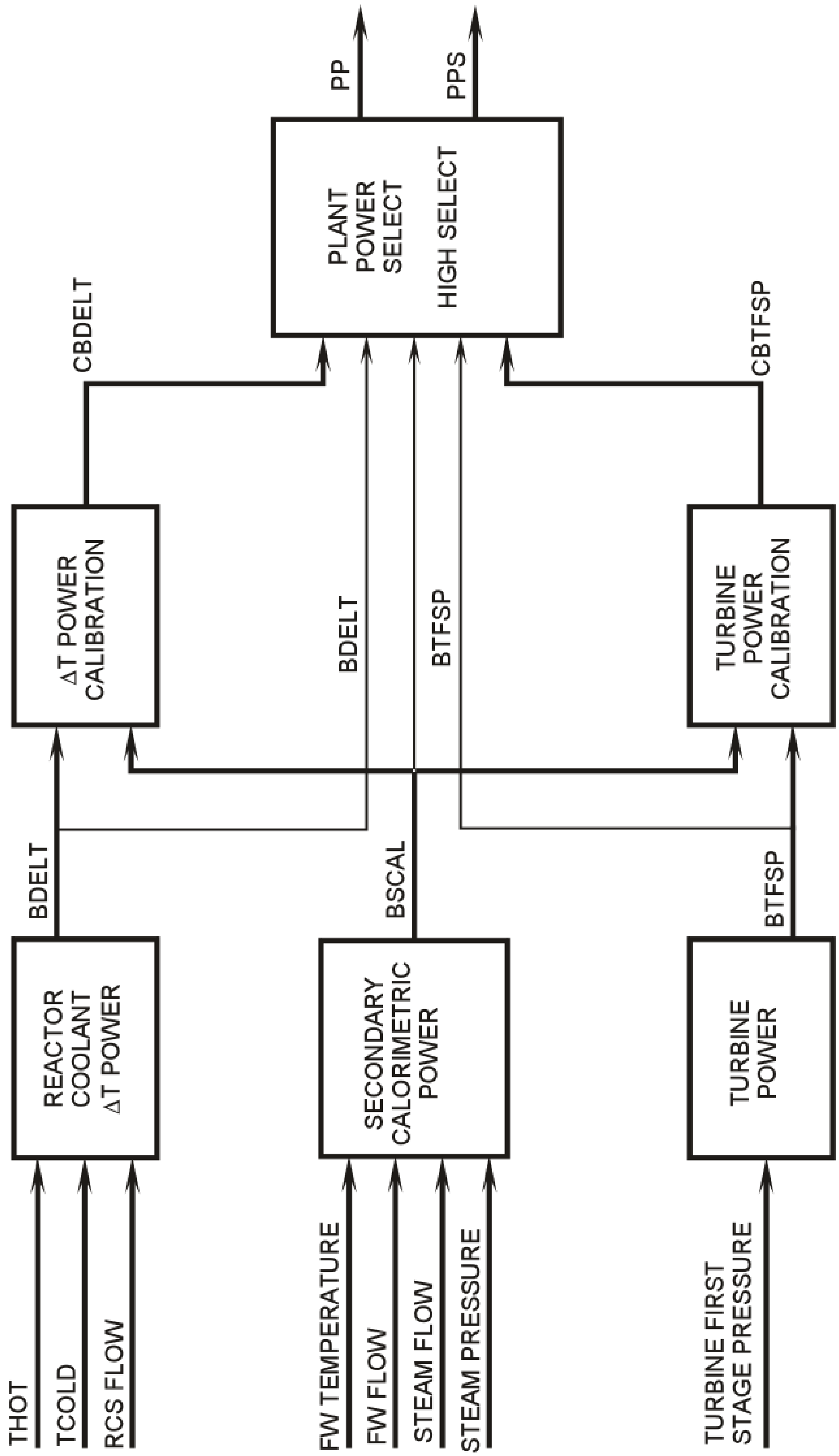


Figure 12.3-4 Power Calculations – Normal Power above 15%

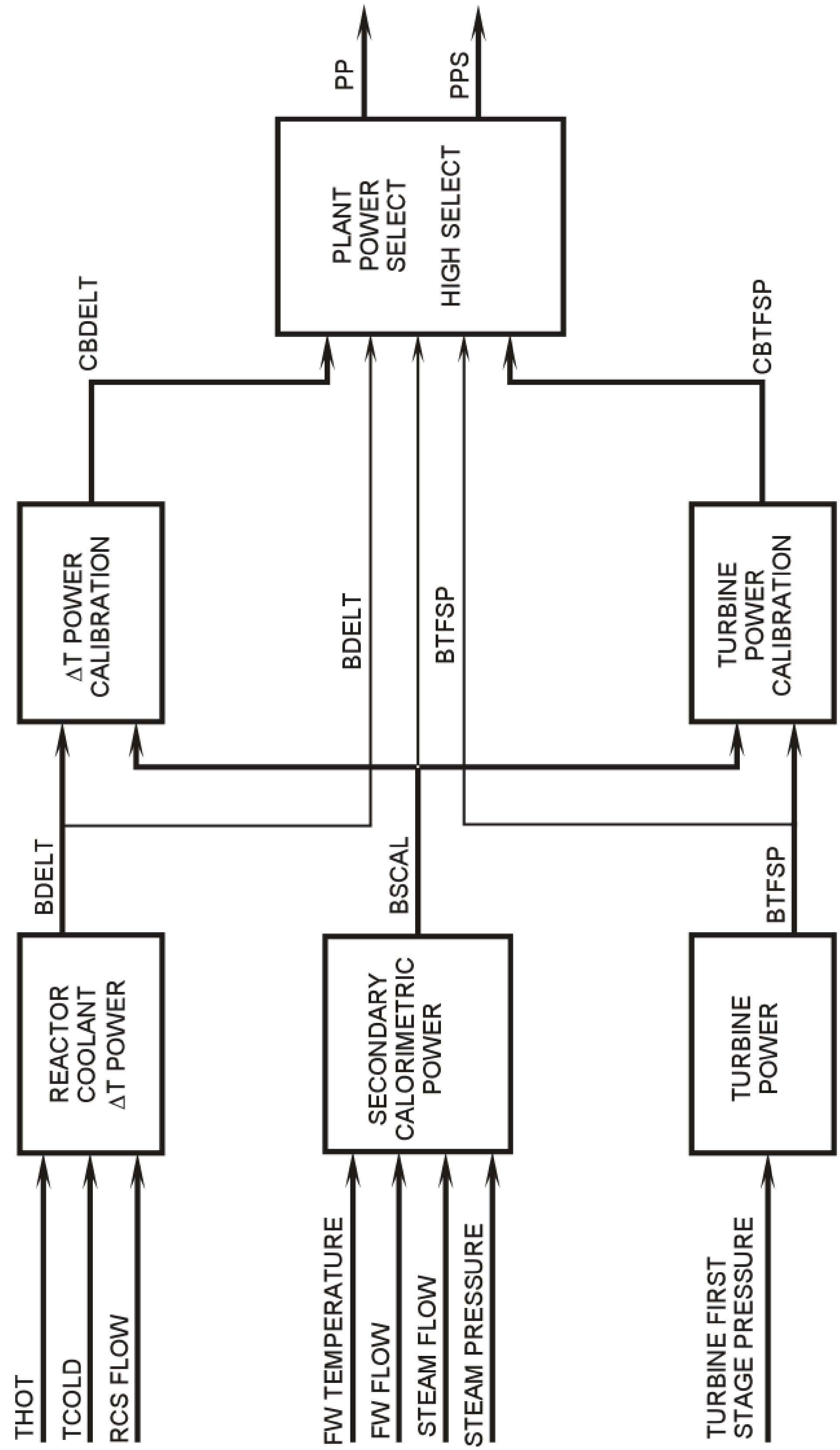


Figure 12.3-5 Power Calculations – Power Operation Below 15% with BSCAL Bad

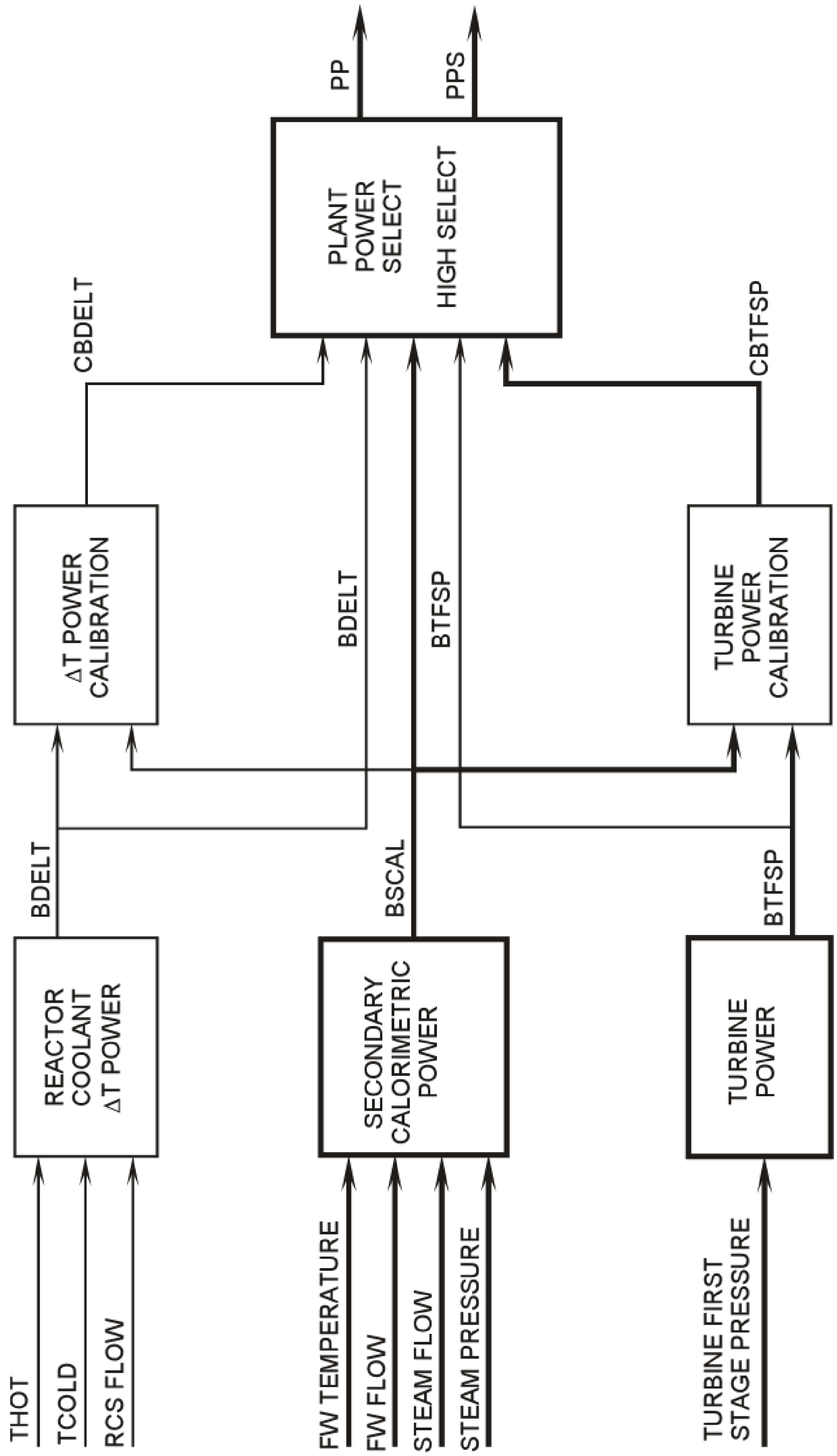


Figure 12.3-6 Power Calculations – Power Operation above 15% BDELT Bad

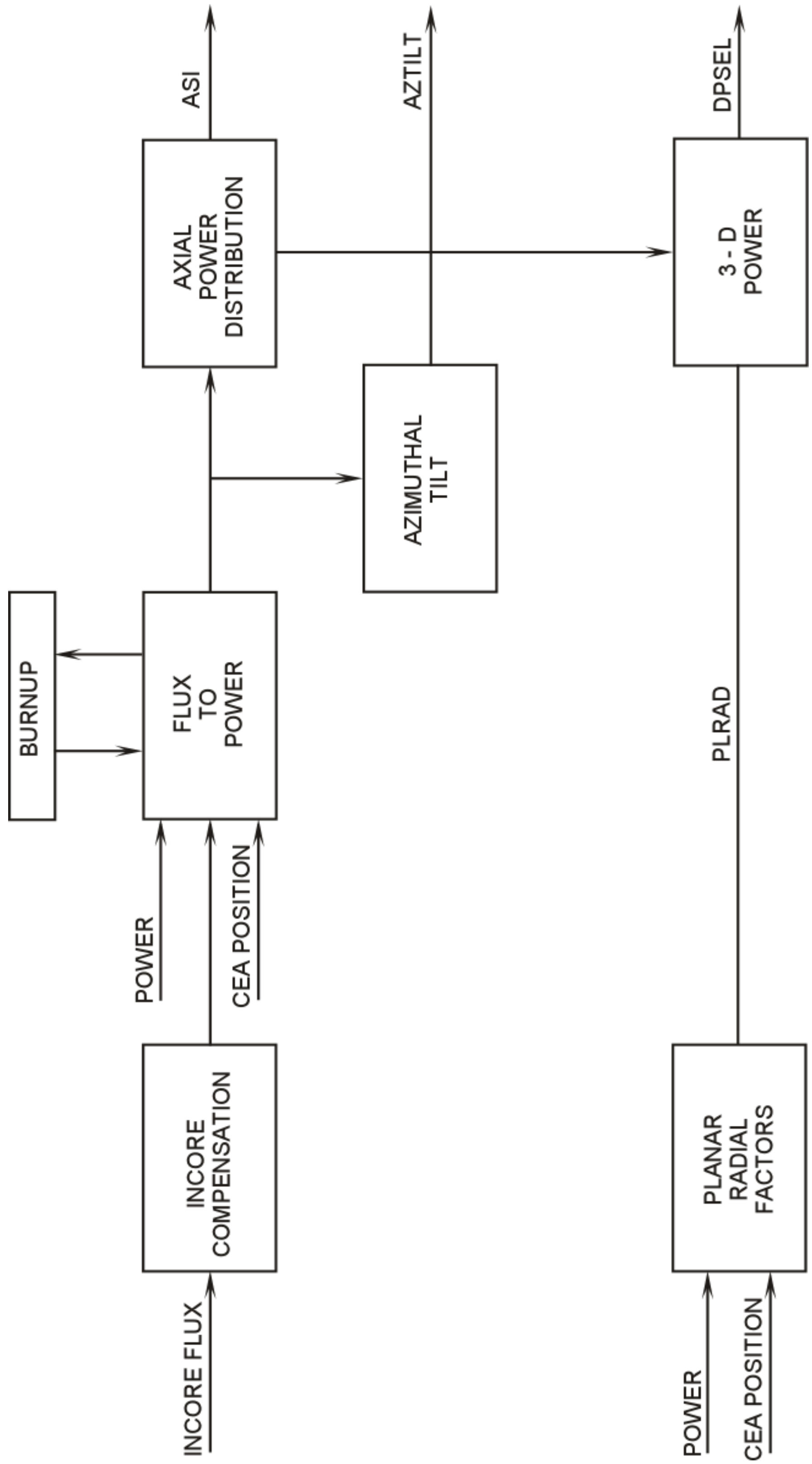


Figure 12.3-7 Power Distribution